FIBER OPTICS — Part 1

Fiber optics are the latest transmission media in communications and instrumentation technology. Fibers are showing up in telecommunications, in computer data communications, and all manner of scientific, engineering and medical instruments. Briefly stated, fiber optics is that technology in which light is passed through a plastic or glass fiber so that it can be directed to a specific destination. If the light is encoded (modulated) with an information signal, then that signal is transmitted over the fiber optical path.

Joseph J. Carr

THERE are many advantages to the fiber optical communications or data link, including:

- Very high bandwidth (accommodates video signals, many voice channels, or high data rates in computer communications).
- Very low weight and small size.
- Low loss compared with other media.
- Freedom from electromagnetic interference (EMI).
- High degree of electrical isolation.
- Explosion proof.
- Good data security
- Improved 'fail-safe' capability.

The utility of the high bandwidth capability of the fiber optical data link is that it can handle a tremendous amount of electronically transmitted information simultaneously. For example, it can handle more than one video signal (which typically requires 500 kHz to 10 MHz of bandwidth, depending on resolution). Alternatively, it can handle a tremendous number of voice communication telephony channels (which is why you see those advertisements on television). High speed computer data communications capability is also possible. Either a few channels can be operated at extremely high speeds, or a larger number of low-speed parallel data channels are available on the fiber. Fiber optics are so significant, that one can expect to see them proliferate in the communications industry for years to come. Indeed, some futurists are calling for an extensive nationwide fiber optic communications network for data communications that is the info-age equivalent of the interstate highway system.

The light weight and small size of fiber optics, coupled with relatively low loss, makes the fiber optic communications link a very good economic advantage when large numbers of channels are contemplated. To obtain the same number of channels using coaxial cables or 'paired wires' the system would require a considerably larger, bulkier and heavier, infrastructure.

Electromagnetic interference (EMI) has been a destructive factor in electronics since Marconi and DeForest interfered with each other in radio trials for the Newport Yacht Races just prior to the turn of the 20th century. Today, EMI can be more than merely annoying, and can cause tragic accidents. For example, airliners are operated more and more from digital computers. Indeed, one airline co-pilot recently quipped (about modern aircraft) that one does not need to know how to fly anymore, but one does need to be able to type on a computer keyboard at 80 words per minute. While the pilot's comment was meant to be a joke, it points out just how dependent aircraft have become on modern digital computers and intercommunication between digital devices. If a radio transmitter, radar, or electrical motor is near one of the intercommunications lines, then it is possible to either introduce false data or corrupt existing data with potentially disastrous results. Because the EMI is caused by electrical or magnetic fields coupling between electrical cables, fiber optics (being free of such fields) produces dramatic freedom from EMI.

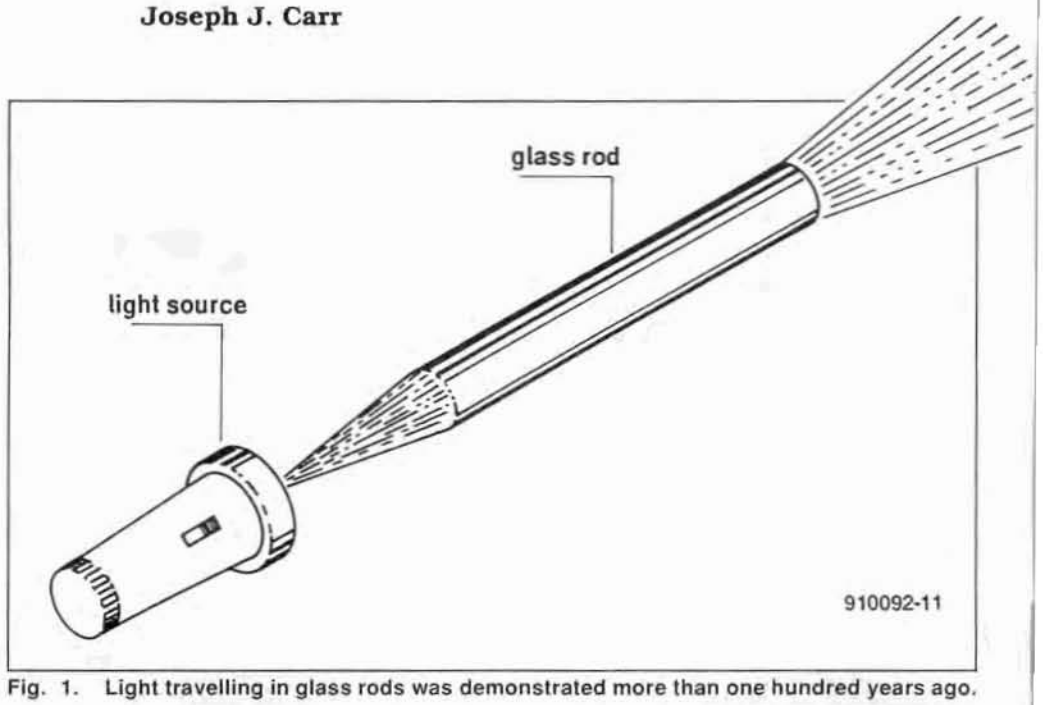


Fig. 1. Light travelling in glass rods was demonstrated more than one hundred years ago.

Electrical isolation is required in many instrumentation systems either for the safety of the user, or the health of the electronic circuits connected to the system. For example, in some industrial processes, high electrical voltages are used, but the electronic instruments used to monitor the process are both low-voltage and ground referenced. As a result, the high voltage can damage the instruments. In fiber optical systems, it is possible to use an electrically floating sensor, and then transmit the data over a fiber link to an electrically grounded, low-voltage computer, instrument or control system.

The fact that fiber optics uses light beams, and these are generated in non-contacting electronic circuits, make the fiber optic system ideal for use in switching and control systems around flammable gases or fumes. For example, in monitoring gasoline systems, or in cases where natural gas or medical anesthetic agents such as ether or cyclopropane[1] are used. Regular mechanical switches or relays are either on contact, or when decontacting, and those sparks can create an explosion if flammable gases or fumes are present. A number of operating room explosions in hospitals occurred prior to about 1960, and some gasoline stations have exploded because of arcing in electrical switches.

System security is enhanced because fiber op-

[1] These agents are only rarely used today, being considered too dangerous since the late 1970s when non-flammable substitutes became widely used.

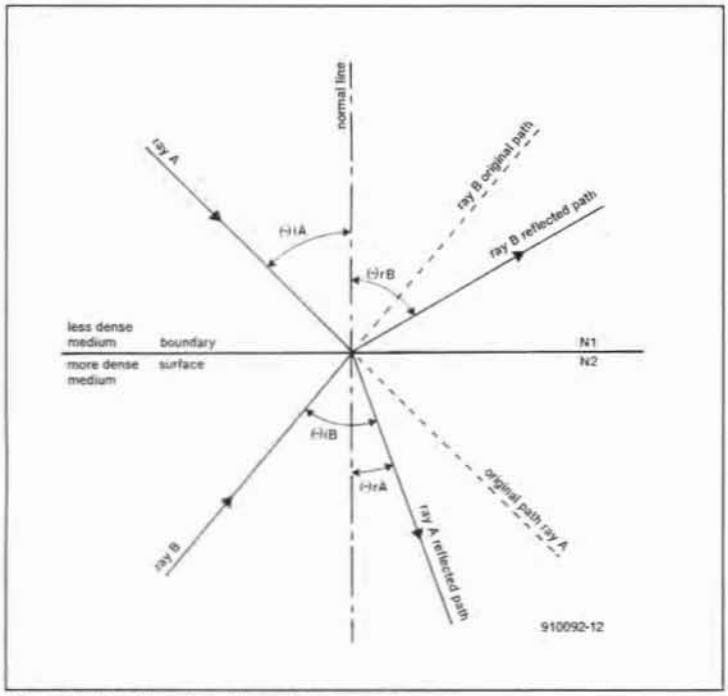


Fig. 2. Basic refraction phenomenon.

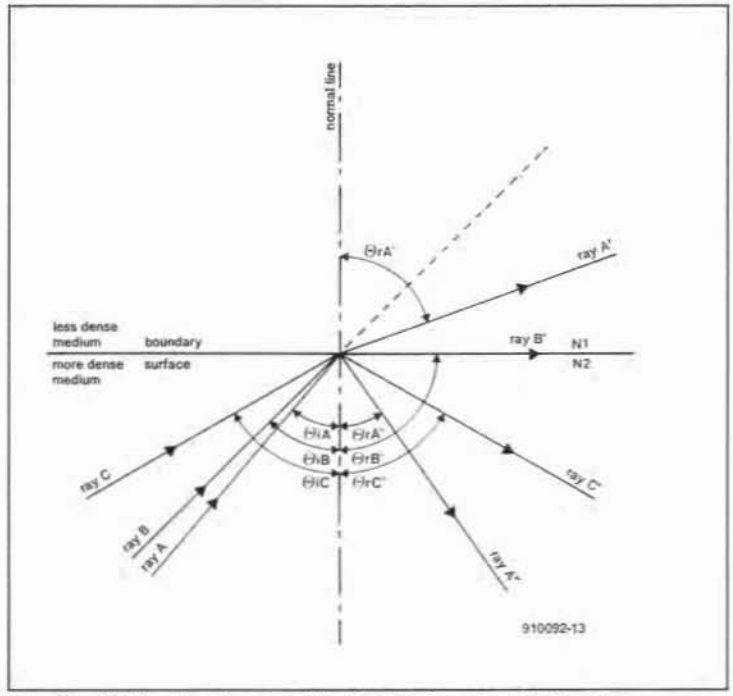


Fig. 3. Refraction involved in 'total internal reflection'.

tics is difficult to tap. An actual physical connection must be made to the system. In wire systems, capacitive or inductive pick-ups can acquire signals with less than total physical connection, i.e., no splice is needed. Similarly, a system is more secure in another sense of the word because the fiber optical transmitters and receivers can be designed to fail safe so that one fault does not take down the system. I recall a hospital coronary care unit data system that used parallel wire connections between the data output ports on bedside monitors and the central monitoring computer at the nurses station. A single short circuit in parallel data lines would reduce the system to chaos! That is less likely to happen in a fiber optical system.

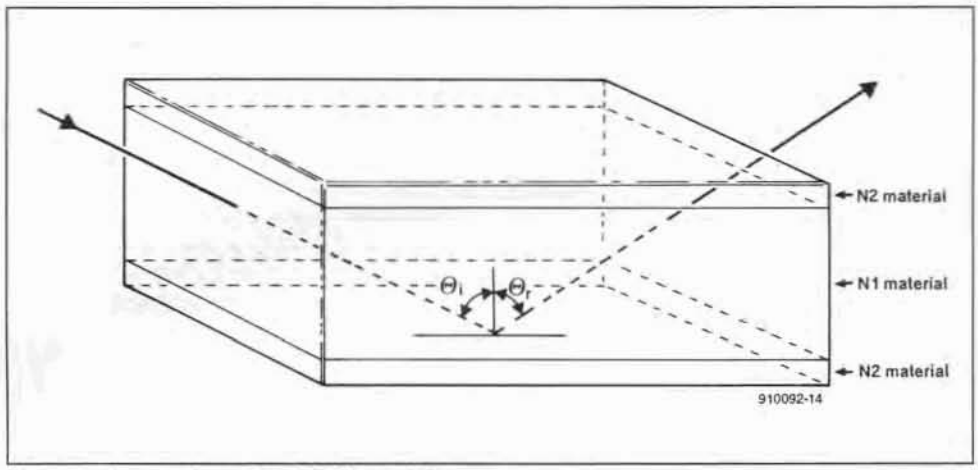


Fig. 4 Waveguide analogy to fiber optics.

Fiber optics: history and practical applications

The basic fact of fiber optics, i.e., the propagation of light beams in a transparent glass conductor (Fig. 1), was noted in the early 1870s when John Tyndall introduced members of The Royal Society to his experimental apparatus. An early, but not very practical, colour television system patented by J.L. Baird used glass rods to carry the colour information. By 1966, G. Hockham and C. Kao (Great Britain) demonstrated a system in which light beams carried data communications via glass fibers. The significant fact that made the Hockham/Kao system work was the reduction of loss in the glass dielectric material to a reasonable level. By 1970, practical fiber optic communications was possible.

Medicine has made use of fiber optics for more than two decades. Fiber optic endoscopes can be passed into various orifices of the body, either natural or surgically made, to inspect the interior of a patient's body. Typically there are two bundles, one for viewing and one for passing a light from a (misnamed) 'cold' light source into the body. For example, gynaecologists can inspect and operate on certain internal organs in females using a laprascope introduced through a 'band-aid' incision in the abdomen. Knee surgeons can use a fiber optic arthroscope to perform nearly miraculous operations on the human knee with far less trauma than previous procedures. Other physicians use fiber optic endoscopes to inspect the stomach and gastric track. A probe is passed through the mouth or nose, down the esophagus into the stomach so that tumors and ulcers can be inspected without resort to surgery. In more recent times, miniature TV cameras using CCD arrays have been made available, with the fiber optics carrying the light into the stomach.

Fiber optic inspection is used elsewhere than in medicine. For example, I recall an advertisement for a septic tank service company that used fiber optics and television to inspect the tank; similarly for plumbers. Other industrial and residential services also use fiber optics to inspect areas that are either inaccessible or too dangerous for direct viewing.

Before examining fiber optic technology, it is useful to discuss some of the basics of optical systems as applied to the fiber optic system.

Review of some basics

The index of refraction (n), or refractive index of a material, is the ratio of the speed of the light wave in a vacuum to the speed of the light wave in the material (e.g., glass, plastic, water). For practical purposes, the speed of light in air is close enough to the speed in a vacuum to be considered the same. Mathematically, the index of refraction, n, is:

$$n = \frac{c}{v_m} \qquad [1]$$

where

c is the speed of light in a vacuum (approx. 3×10^8 m/s);

v_m is the speed of light in the medium.

Refraction is the phenomenon in which a light ray changes direction as it passes across the boundary surface (or 'interface') between two mediums of differing indices of refraction ($n_1 \neq n_2$). Consider Fig. 2 in which two materials, with indices of refraction n_1 and n_2 respectively. Consider incident lightray A, approaching the interface from the less dense side ($n_1 \rightarrow n_2$). As it crosses the interface it changes direction towards a line normal (i.e., at right angles) to the surface. Conversely, lightray (B) approaches the interface from the

more dense side ($n_2 \rightarrow n_1$). In this case, the lightray is similarly refracted from its original path, but the direction of refraction is away from the normal line.

In refractive systems the angle of refraction is a function of the ratio of the two indices of refraction, i.e., it obeys Snell's law:

$$n_1 \sin \Theta_{i\,a} = n_2 \sin \Theta_{r\,a} \qquad [2]$$

or,

$$\frac{n_1}{n_2} = \frac{\sin \Theta_{r\,a}}{\sin \Theta_{i\,a}} \qquad [3]$$

The particular case which concerns fiber optics is where the light ray passes from a more dense medium to a less dense medium. We can use either a water to air system, or a system in which two different glasses, with dissimilar indices of refraction, are interfaced. This type of system was addressed in Fig. 2 by ray B. Figure 3 shows a similar system with three different lightrays (ray A, ray B and ray C) approach the same point on the interface from three different angles (i_a, i_b and i_c, respectively). Ray A approaches at a subcritical angle, so it will split into two portions (A' and A"). The reflected portion (A") contains a relatively small amount of the original light energy, and may indeed be nearly indiscernible. The major portion of the light energy is transmitted across the boundary, and refracts at an angle r_a' in the usual manner.

Lightray B, on the other hand, approaches the interface at the critical angle, r_b', and is refracted along a line that is orthogonal to the normal line, i.e., it travels along the interface boundary surface. This angle is normally labelled C in optical textbooks.

Finally, ray C approaches the interface at an angle greater than the critical angle, i.e., a supercritical angle. None of this ray is transmitted across the boundary, but rather it is turned back into the original media; i.e., it is subject to total internal reflection (TIR). It is the phenomenon of total internal reflection that allows fiber optics to work.

Fiber optics

The fiber optic is somewhat similar to a microwave waveguide, and an understanding of waveguide action is useful in understanding fiber optics. A schematic model of a fiber optic is shown in Fig. 4. A slab of denser material (n_1) is sandwiched between two slabs of a less dense material (n_2). Lightrays that approach from a supercritical angle are totally internally reflected from the two interfaces ($n_2 \rightarrow n_1$ and $n_1 \rightarrow n_2$). Although only one 'bounce' is shown in our illustration, the ray will be subjected to successive TIR reflections as it propagates through the n_1 material. The amount of light energy that is reflected through the TIR mechanism is of the order of 99.9 per cent, which compares quite favourably with the 85-96 per cent typically found in planar mirrors.

Fiber optic lines are not rectangular, but rather are cylindrical, as shown in Fig. 5. These components are called clad fiber optics because the denser inner core is surrounded by a less dense layer called cladding. Shown in Fig. 5 are two rays, each of which is propagated into the system such that the critical angles are exceeded. These rays will propagate down the cylindrical optical fiber with very little loss of energy. There are actually two forms of propagation. The minority form (Fig. 6a), called meridional rays, are easier to understand and mathematically model in textbooks because all rays lie in a plane with the optical axis. The more numerous skew rays (Fig. 6b) follow a helical path, so are somewhat more difficult to discuss (Ref. 1).

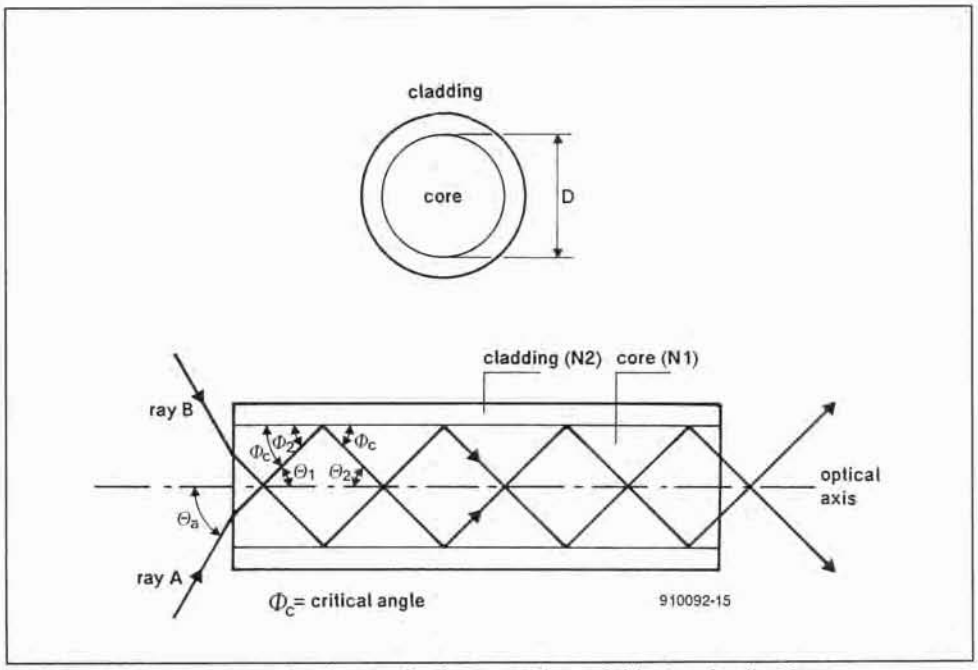


Fig. 5. Light propagates in fiber optics by repetitive total internal reflection.

The light acceptance of the fiber optic (Fig. 7) is a cone shaped region centred on the optical axis. The acceptance angle a is the critical angle for the transition from air ($n = n_a$) to the core material ($n = n_a$). The ability to collect light is directly related to the size of the acceptance cone, and is expressed in terms of the numerical aperture, NA, which is:

$$NA = \sin \Theta_a \qquad [4]$$

The refraction angle of the rays internally, across the air-n_1 interface, is given by Snell's law:

$$\Theta_{b\,i} = \arcsin\left(\frac{n_a \sin \Theta_a}{n_1}\right) \qquad [5]$$

In terms of the relative indices of refraction between the ambient environment outside the fiber, the core of the fiber and the cladding material, the numerical aperture is given by:

$$NA = \sin \Theta_a = \frac{1}{n_a}\sqrt{n_1^2 - n_2^2} \qquad [6]$$

If the ambient material is air, then the numerical aperture equation reduces to:

$$NA = \sqrt{n_1^2 - n_2^2} \qquad [7]$$

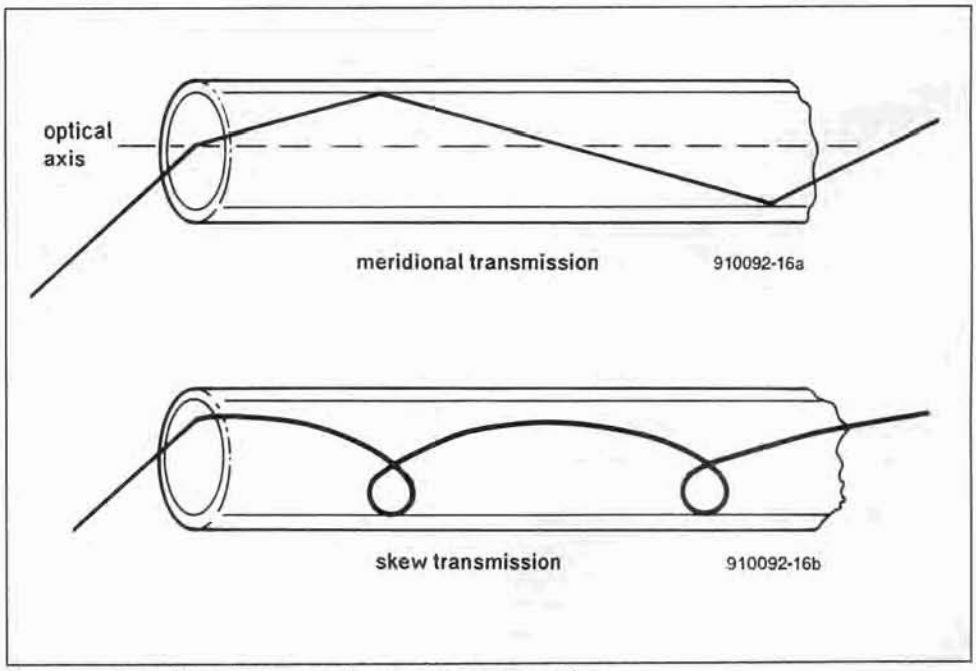


Fig. 6. a) meridional propagation; b) skew propagation.

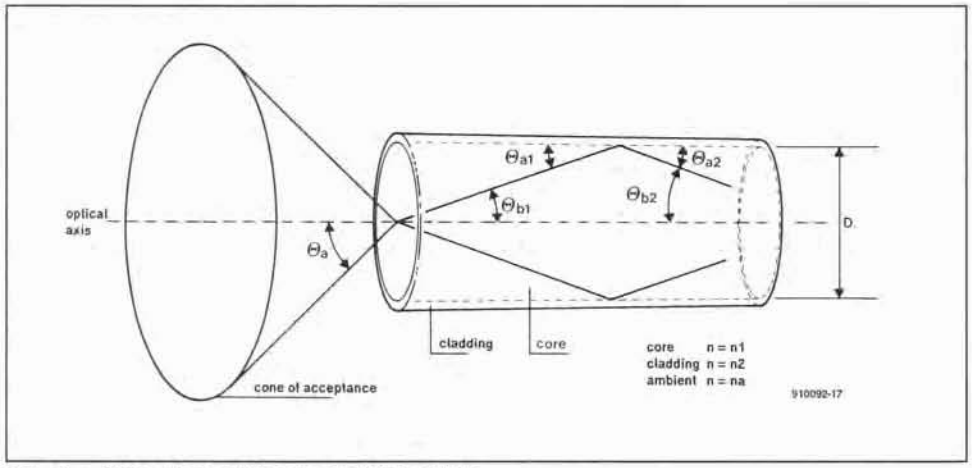


Fig. 7. Cone of acceptance of a fiber cable.

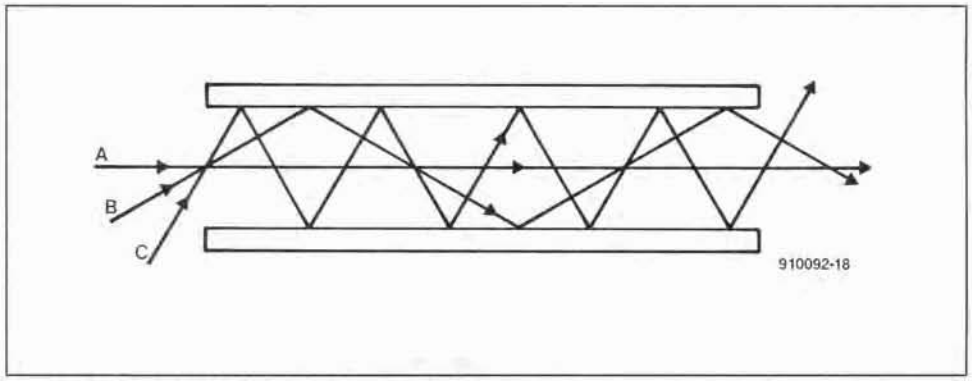


Fig. 8. Transmission modes in fiber optics.

Internally, the angles of reflection (a_1 and a_2), at the critical angle, are determined by the relationship between the indices of refraction of the two materials, n_1 and n_2:

$$\Theta_{a1} = \frac{\arcsin\sqrt{n_1^2 - n_2^2}}{n_1} \qquad [8]$$

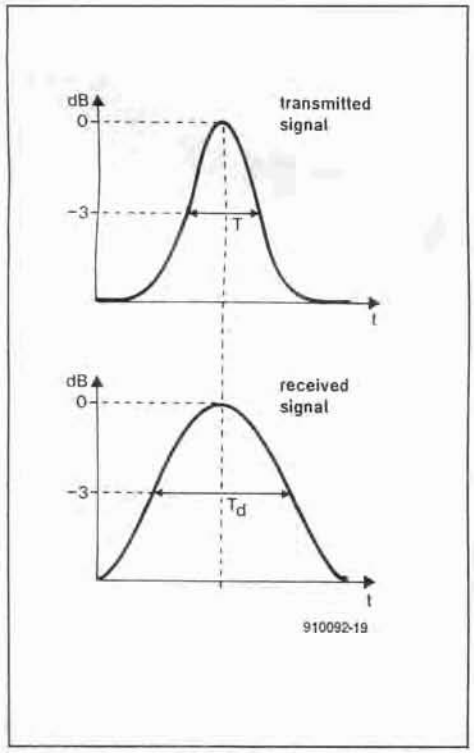


Fig. 9. a) input light pulse; b) output pulse is dispersed in time.

Typical fiber optic components have numerical apertures of 0.1 to 0.5; typical fibers have a diameter D of 25 µm to 650 µm. The ability of the device to collect light is proportional to the square of the numerical aperture:

$$\zeta \equiv (\mathrm{NA} \times D)^2 \qquad [9]$$

Intermodal dispersion

When a light ray is launched in a fiber optic it can take any of a number of different paths, depending in part on its angle of arrival (Fig. 8). These paths are known as transmission modes, and vary from very low order modes parallel to the optical axis of the fiber (ray A in Fig. 8), to the highest order mode close to the critical angle (ray C); in addition, there are a very large number of rays in between these two limits. An important feature of the different modes is that the respective path lengths vary tremendously, being shortest with the low order modes and longest with high order modes. If a fiber optic has only a single core and single layer of cladding, it is called a step index fiber because the index of refraction changes abruptly from the core to the cladding. The number of modes, N, that can be supported are given by:

$$N = \frac{(\pi D\,[\mathrm{NA}]/\lambda)^2}{2} \qquad [10]$$

Any fiber with a core diameter, D, greater than about ten wavelengths (10λ) will support a very large number of modes, so is typically called a multimode fiber. A typical light beam launched into such a step index fiber optic will simultaneously find a large number of modes available to it. This may or may not affect analogue signals, but has a deleterious effect on digital signals called intermodal dispersion.

Figure 9 illustrates the effect of intermodal dispersion on a digital signal. When a short duration light pulse (Fig. 9a) is applied to a fiber optic that exhibits a high degree of intermodal dispersion, the received signal (9b) is smeared, or 'dispersed', over a wider area. At slow data rates this effect may prove negligible because the dispersed signal can die out before the next pulse arrives. But at high speeds, the pulses may overrun each other (Fig. 10), producing an ambiguous situation that potentially exhibits a high data error rate.

Intermodal dispersion is usually measured relative to the widths of the pulses at the –3 dB (i.e., half-power) points. In Fig. 9, the –3-dB point on the incident pulse transmitted into the fiber optic is T, while in the received pulse the time between –3 dB points is T_d. The dispersion is expressed as the difference, or:

$$\text{Dispersion} = T - T_d \qquad [11]$$

A means for measuring the dispersion for any given fiber optic element is to measure the dispersion of a Gaussian (normal distribution) pulse at those –3-dB points. The cable is then rated in terms of nanoseconds dispersion per kilometre of fiber (ns/km).

The bandwidth of the fiber, in megahertz per kilometre (MHz/km), can be specified from knowledge of the dispersion, using the expression:

$$\mathrm{B\,(MHz/km)} = \frac{310}{\mathrm{Disp.(ns/km)}} \qquad [12]$$

Graded index fibers

A solution to the dispersion problem is to build a fiber optic with a continuously varying index of refraction such that n decreases at distances away from the optical axis. While such smoothly varying fibers are not easy to build, it is possible to produce a fiber optic with layers of differing index of refraction (Fig. 11). The relationship of the respective values of n for each layer are:

$$n_1 > n_2 > n_3 > n_4 > n_5 > \ldots n_i \qquad [13]$$

The overall index of refraction determines the numerical aperture, and is taken as an average of the different layers.

With graded fibers, the velocity of propagation of the light ray in the material is faster in the layers away from the optical axis than in the lower layers. As a result, a higher order mode wave will travel faster than a wave in a lower order.

The number of modes available to the graded index fiber are:

$$N = \frac{(\pi D\,[\mathrm{NA}]/\lambda)^2}{4} \qquad [14]$$

Some cables operate in a critical mode, designated HE_{11} (to borrow from microwave terminology) in which the cable is very thin compared with multimodal cables. As the diameter of the core decreases, so does the number of available

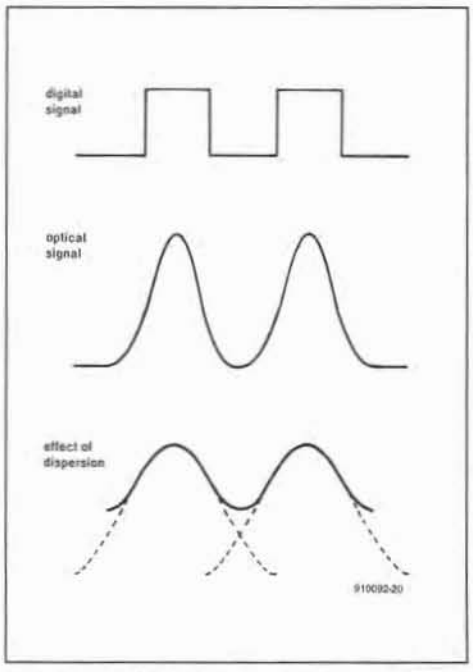


Fig. 10. Effects of dispersion on digital signal bandwidth: a) original data signal; b) light pulse inputto fiber system; c) dispersed light pulses overlapped.

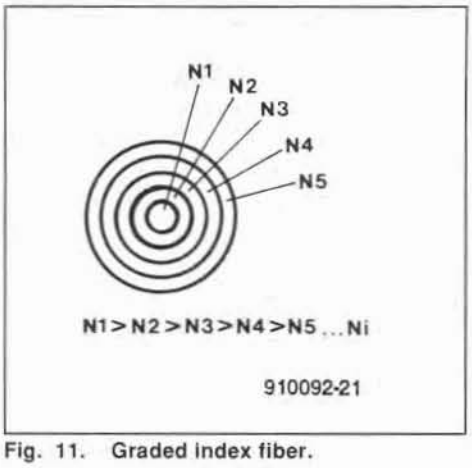


Fig. 11. Graded index fiber.

modes and eventually the cable becomes monomodal; If the core gets down to 3 to 5 microns, then only the HE_{11} mode becomes available. The critical diameter required for monomodal operation is:

$$D_{crit} = \frac{2.4\lambda}{\pi\,[NA]} \qquad [15]$$

Because the monomodal cable potentially reduces the number of available modes, it also reduces intermodal dispersion. Thus, the monomode fiber is capable of extremely high data rates or analogue bandwidths.

Next month...

In the second and final instalment of this article we will take a look at losses in fiber optic systems, fiber optic communications and some of the basic driver and receiver circuits needed to make fiber optics work. ❑

Reference:

1. "Optical-fibre communication" *Elektor Electronics* February 1991.

CORRECTIONS

Wattmeter

April 1991, p. 32-35

With reference the circuit diagram, Fig. 1, the right-hand terminal of the lower section of switch S2 should be connected to the circuit ground. This point is indicated by a dot.

In the adjustment procedure given on page 35, the references to presets P4 and P5 have been transposed. Contrary to what is stated, P4 sets the VY offset, and P5 the VX offset. The functions of the presets are shown correctly in the circuit diagram, Fig. 1.

To improve the accuracy of the instrument, connect R5 direct to the circuit ground instead of junction R6-R7. Finally, all circuit board tracks carrying mains current must be strengthened with 2.5-mm² cross-sectional area solid copper wire if currents higher than about 5 A are measured.

80C32/8052 Single-board computer

May 1991, p. 17-23

When a CPU type 8031 or 8052AH-BASIC is used, IC1, IC2, IC3, and IC8-IC12 must be 74HCT types. Jumper B is erroneously reffered to as Br2 in the text under "On-board EPROM programmer". Contrary to what is stated, this jumper must be fitted only when an EPROM is to be programmed — for all other use of the SBC, it must be removed. Also note that jumper B may only be fitted when the programming LED is out.

Sequential control

July/August 1991, p. 61

Motor M should be a d.c. type, not an a.c. type as shown in the circuit diagram.

Digital phase meter

June 1991, p. 32-39

In Fig. 5, the switch between input 'A' and IC1 should be identified 'S1', and that between input 'B' and IC2 'S2'. Switch S4 is an on/off type, not a push-button as shown in the diagram. Capacitors C3 and C6 are shown with the wrong polarity. The component overlay of the relevant printed-circuit board (Fig. 8) is all right.

Universal NiCd battery charger

June 1991, p. 14-19

The parts list on page 19 should be corrected to read

C7 = 2200µF 25V

When difficult to obtain, the BYW29/100 (D5) may be replaced by the BY229, which is rated at 6 A.

The text under the heading 'Calibration' should be replaced by:

4. Connect a multimeter between points G and H on the board, and adjust P4 until the measured voltage is 1 V lower than the voltage on the battery terminals.

MIDI program changer

April 1991, p. 14-17

The contents of the EPROM should be modified as follows:

address	data
OOBC	E5
00C7	80
00C8	CB
00C9	F5
00CA	7B
00CB	12
00CC	00
00CD	D2
00CE	C2
00CF	02
00D0	80
00D1	C2

Readers who have obtained the EPROM ready-programmed through the Readers Services may return it to obtain an update.

Electronic exposure timer

March 1991, p. 31-35

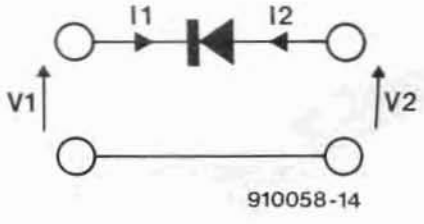
Please add to the parts list on page 32:

C16 = 33 pF

Augmented A-matrices

May 1991, p. 42-43

The drawing below was erroneously omitted in the left-hand bottom corner of page 43.



Fiber Optics — Part 2

Last month we discussed the basic theory behind optical fiber systems. It was learned that fiber optics are the light equivalent of microwave waveguides, and that they are capable of immense bandwidth communications. In this month's final instalment we will look at fiber communications and some of the circuits that can be used with experimenter grade optical fiber kits.

by Joseph J. Carr

Losses in optical fiber systems

Decibel notation can be used for optical fiber systems and refers to the gain or loss of each stage or component in the system. The dBkm scale uses decibels of gain or loss relative to the attenuation of a standard optical fiber section over a one kilometre (1 km) length. Alternatively, either dBmi (dB loss relative to attenuation over 1 mile) or dBl (a normalized unit length) can be used.

The light power at the output end of a optical fiber (P_o) is reduced compared with the input light power (P_{in}) because of losses in the system. As in many natural systems, light loss in the fiber material tends to be decaying exponentially (Fig. 1a), so obeys an equation of the form:

$$P_o = P_{in}\, e^{(-\Lambda / L)} \qquad [1]$$

Where:

Λ is the length of the optical fiber being considered;

L is the unit length, i.e., the length for which $e^{-\Lambda/L} = e^{-1}$.

There are several mechanisms for loss in fiber optics systems. Some of these are inherent in any light-based system, while others are a function of the design of the specific system being considered.

Defect losses

Figure 1b shows several possible sources of loss owing to defects in the fiber itself. First, in unclad fibers, surface defects (nicks or scratches) that breech the integrity of the surface will allow light to escape. In other words, not all of the light is propagated along the fiber. Second (also in unclad fibers), grease, oil or other contaminants on the surface of the fiber may form an area with an index of refraction different from what is expected and cause the light direction to change. And if the contaminant has an index of refraction similar to glass, then it may act as if it were glass and cause loss of light to the outside world. Finally, there is always the possibility of inclusions, i.e., objects, specks or voids in the material making up the optical fiber. Inclusions can affect both clad and unclad fibers. When light hits the inclusion it tends to scatter in all directions, causing a loss. Some of the light rays scattered from the inclusion may recombine either destructively or constructively with the main ray, but most do not.

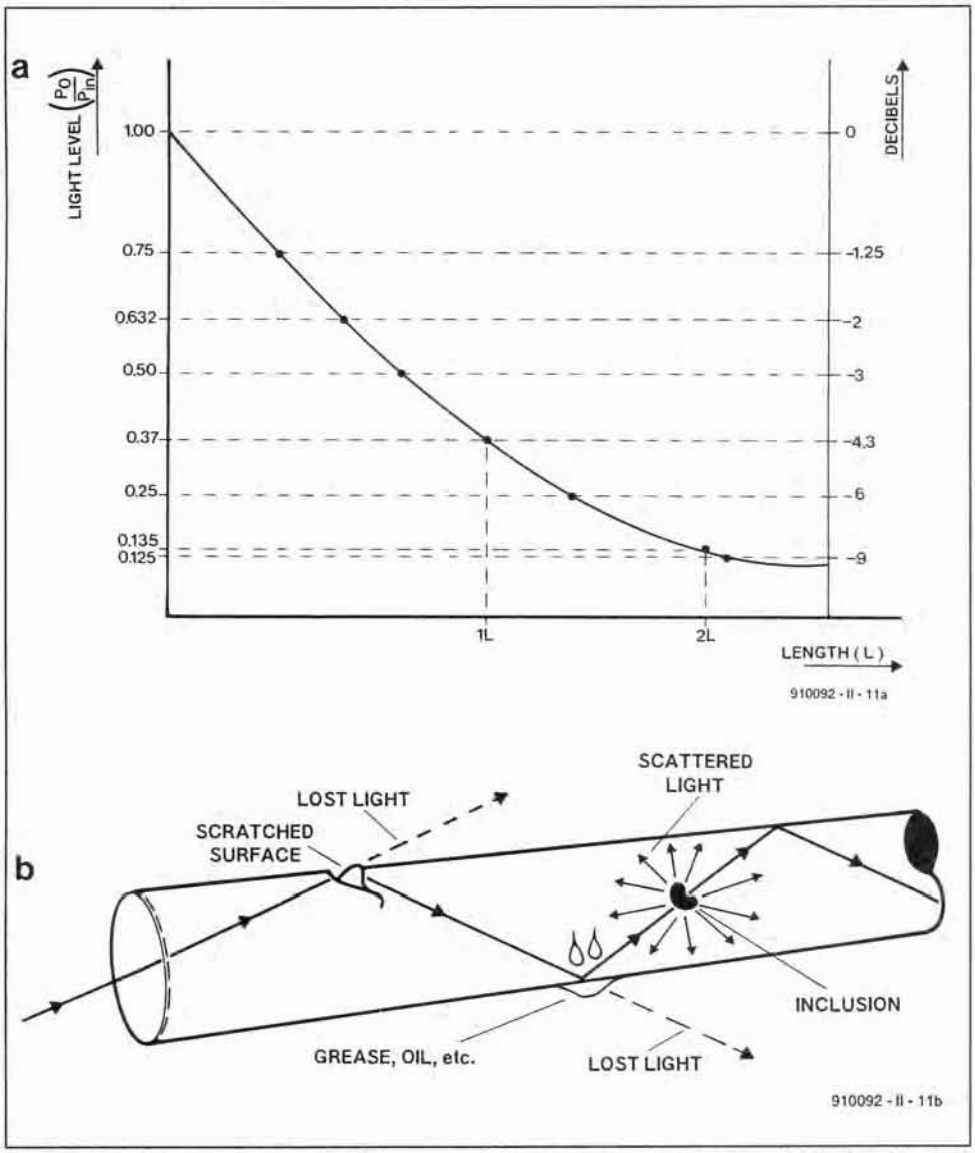


Fig. 1. (a) Exponential decay of signal strength along an optical fiber; (b) mechanisms of loss in fibers.

Inverse square law losses

In all light systems there is the possibility of losses caused by spreading (divergence) of the beam. If you take a flashlight and point it at a wall, and measure the illuminance per unit area at the wall at a distance of, say, one meter, and then back off to twice the distance (two meters) and then measure again, you will find that the illuminance has dropped to one-fourth. In other words, the illuminance per unit area is inversely proportional to the square of the distance ($1/d^2$).

Transmission losses

These losses are caused by light that is caught in the cladding material of clad optical fibers. This

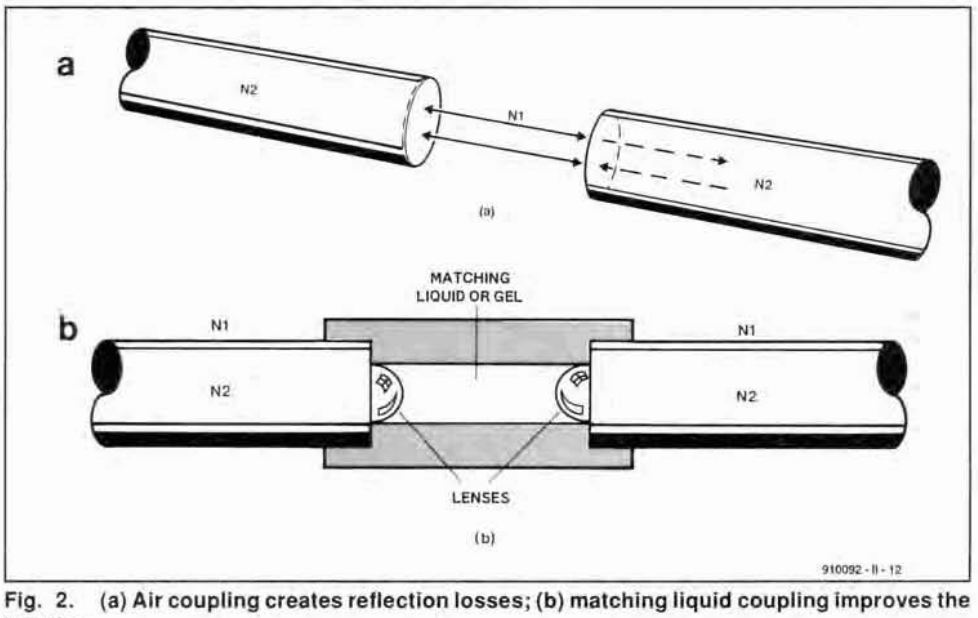


Fig. 2. (a) Air coupling creates reflection losses; (b) matching liquid coupling improves the junction.

light is either lost to the outside, or is trapped in the cladding layer and is thus not available for propagation in the core.

Absorption losses

This form of loss is caused by the nature of the core material, and is inversely proportional to the transparency of the material. In addition, in some materials absorption losses are not uniform across the light spectrum, but are thought to be wavelength sensitive.

Coupling losses

Another form of loss is caused by coupling systems. All couplings (of which more is said later) have loss associated with them. Several different losses of this sort are identified.

Mismatched fiber diameters

This form of loss is caused by coupling a large diameter fiber (D_L) to a small diameter fiber (D_S); i.e., the larger diameter fiber transmits to the lesser diameter fiber. As a ratio, this loss is expressed by:

$$\text{loss} = -10 \log\left(\frac{D_S}{D_L}\right) \quad \text{(dB)} \qquad [2]$$

Numerical aperture (NA) coupling losses

Another form of coupling loss occurs when the numerical apertures of the two fibers are mismatched. If NA_R is the numerical aperture of the receiving fiber, and NA_T that of the transmitting fiber, then the loss is expressed as:

$$\text{loss} = -10 \log\left(\frac{NA_R}{NA_T}\right) \quad \text{(dB)} \qquad [3]$$

Fresnel reflection losses

These losses occur at the interface between the optical fiber and air—see Fig. 2a—and are caused by the large change of refractive index at the glass-air barrier. There are actually two losses to consider. First is the loss caused by internal reflection from the inner surface of the interface, while the second is caused by reflection from the opposite surface across the air gap in the coupling. Typically, the internal reflection loss is of the order of 4 per cent, while the external reflection is about 8 per cent.

Any kind of reflection in an optical transmission system may be compared to reflections in a radio transmission line (standing-wave ratio). Studying standing waves and related subjects in books on RF systems can yield some understanding of these problems. The amount of reflection in coupled optical systems uses similar arithmetic:

$$\Gamma = \left(\frac{\rho_1 - \rho_2}{\rho_1 + \rho_2}\right)^2 \qquad [4]$$

Where:

Γ is the coefficient of reflection;

ρ_1 is the coefficient of reflection for the receiving material;

ρ_2 is the coefficient of reflection for the transmitting material.

Mismatched reflection coefficients are analogous to a mismatch of impedances in a radio transmission system. Whereas the cure in a transmission line system is to use an impedance matching device, in fiber optics, a coupler that matches the 'optical impedances', that is, the coefficients of reflection, is used. Figure 2b shows a coupling between the two ends of fibers (lenses may or may not be used depending on the system). The gel or liquid used to seal the couplings must have a coefficient of reflection similar to that of the fiber. The reflection losses are thereby reduced or even eliminated.

Optical fiber communications systems

A communications system requires an information signal source (e.g., voice, music, digital data, or an analogue voltage representing a physical parameter), a transmitter, a propagation media (in this case optical fibers), a receiver preamplifier, a receiver, and an output. In addition, the transmitter may include any of several different forms of encoder or modulator, and the receiver may contain a decoder or demodulator.

Figure 3 shows two main forms of communications link. The simplex system is shown in Fig. 3a. In this system a single transmitter sends light (information) over the path in only one direction to a receiver set at the other end. The receiver can not reply or otherwise send data back the other way. The simplex system requires only a single transmitter and a single receiver module per channel.

A duplex system (Fig. 3b) is able to simultaneously send data in both directions, allowing both send and receive capability at both ends. The duplex system requires a receiver and a transmitter module at both ends, plus two-way beam splitting Y-couplers at each end.

There is also a half-duplex system known in communications, but this is of little interest here. A half-duplex system can transmit in both directions, but not at the same time.

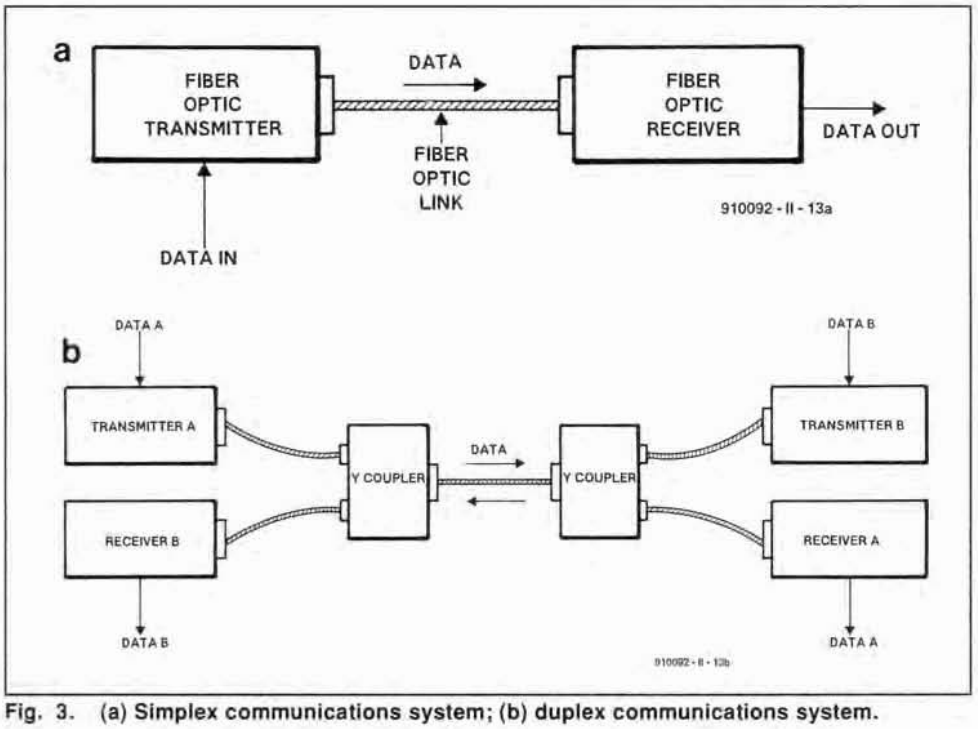


Fig. 3. (a) Simplex communications system; (b) duplex communications system.

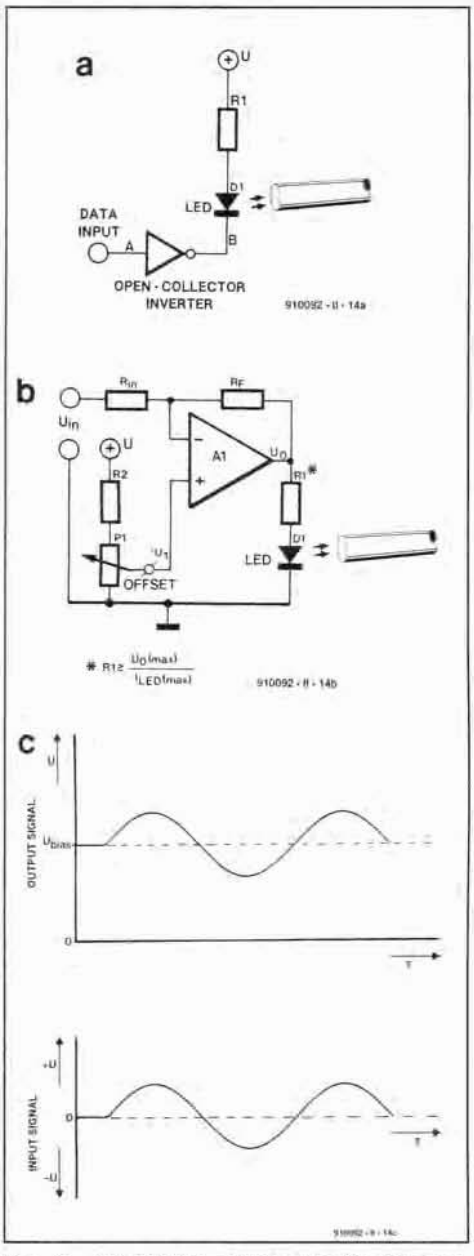


Fig. 4. (a) Digital driver circuit; (b) analogue driver circuit; (c) d.c. offset bias is needed to prevent distortion of the analogue signal.

Receiver amplifier and transmitter driver circuits

Before the fiber optics system is useful for communications, a means must be provided for converting electrical (analogue or digital) signals into light beams. Also necessary is a means for converting the light beams from the optical fibers back into electrical signals. These jobs are done by driver and receiver preamplifier circuits respectively.

Figure 4 shows two possible driver circuits. Both circuits use light emitting diodes (LEDs) as the light source. The circuit in Fig. 4a is useful for digital data communications. The signals are characterized by on/off (high/low or 1/0) states in which the light emitting diode is either on or off, indicating which of the two possible binary digits is required at the moment.

The driver circuit consists of an open-collector digital inverter. These devices obey a very simple rule: if the input (A) is high, the output (B) is low; if the input (A) is low, the output (B) is high. Thus, when the input data signal is high, point B is low, so the cathode of the LED is grounded. The LED turns on and sends a light beam down the optical fiber line. But when the input data line is low, point B is high, so the LED is ungrounded (and therefore turned off) — no light enters the fiber. The resistor (R_1) is used to limit the current flowing in the LED to a safe value. Its resistance is found from Ohm's law and the maximum allowable LED current:

$$R_1 = \frac{(U+) - 0.7}{I_{max}} \qquad [5]$$

An analogue driver circuit suitable for voice and instrumentation signals is shown in Fig. 4b. This circuit is based on an operational amplifier. There are two aspects to this circuit: the signal path and the d.c. offset bias. The latter is needed in order to place the output voltage at a point where the LED lights at about one-half of its maximum brilliance when the input voltage, U_{in}, is zero. That way, negative signals will reduce the LED brightness, but will not turn it off (see Fig. 4c). In other words, biasing avoids clipping of the negative peaks. If the expected signals are monopolar, U_1 is set to barely turn on the LED when the input signal is zero.

The signal U_{in} sees an inverting follower with a gain of R_F/R_{in}, so the total output voltage (accounting for the d.c. bias) is:

$$U_o = \left(\frac{-U_{in} R_F}{R_{in}}\right) + U_1\left(\frac{R_F}{R_{in}} + 1\right) \qquad [6]$$

Because the network R_2/P_1 is a resistor voltage divider, the value of U_1 will vary from 0 volts to a maximum of:

$$U_1 = \frac{(U+)\,P_1}{R_2 + P_1} \qquad [7]$$

Therefore, we may conclude that $U_{o(max)}$ is:

$$U_{o(max)} = \left(\frac{-U_{in} R_F}{R_{in}}\right) + \left(\frac{(U+)\,P_1}{R_2 + P_1}\right)\left(\frac{R_F}{R_{in}} + 1\right) \qquad [8]$$

Three different receiver preamplifier circuits are shown in Fig. 5: analogue versions are shown in Figs. 5a and 5b, while a digital version is shown in Fig. 5c. The analogue versions of the receiver preamplifiers are based on operational amplifiers. Both analogue receiver preamplifiers use a photodiode as the sensor. These p-n or p-i-n junction diodes produce an output current, I_o, that is proportional to the illumination on the diode junction.

The version shown in Fig. 5a is based on the inverting follower circuit. The diode is connected so that its non-inverting input is grounded, i.e., at zero volts potential, and the diode current is applied to the inverting input. The feedback current (I_F) exactly balances the diode current, so the output voltage will be:

$$U_o = -I_o R_F \qquad [9]$$

The non-inverting follower version shown in Fig. 5b uses the diode current to produce a voltage drop (U_1) across a load resistance, R_L. The output voltage for this circuit is:

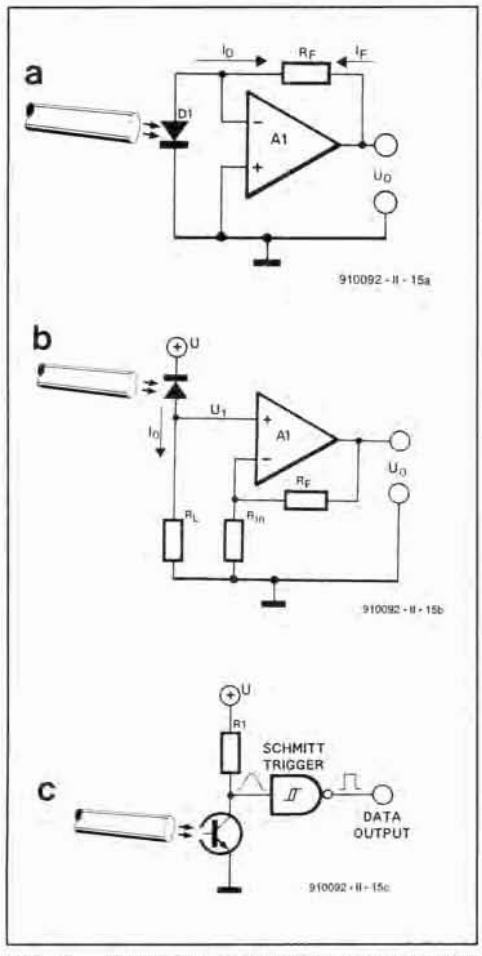


Fig. 5. (a) Inverting follower receiver; (b) non-inverting follower receiver; (c) digital receiver based on Schmitt trigger.

$$U_o = I_o R_L \left(\frac{R_F}{R_{in}} + 1\right) \qquad [10]$$

Both analogue circuits will respond to digital circuits, but they are not at their best for that type of signal. Digital signals will have to be reconstructed because of sloppiness caused by dispersion. A better circuit is that of Fig. 5c. In this circuit, the sensor is a phototransistor connected in the common emitter configuration. When light falls on the base region, the transistor conducts, causing its collector to be at a potential only a few tenths of a volt above ground potential. Conversely, when no light falls on the base, the collector of the transistor is at a potential close to $U+$, the power supply potential.

The clean-up action occurs in the following stage: a Schmitt trigger. The output of such a device will snap high when the input voltage exceeds a certain minimum threshold, and remains high until the input voltage drops below another threshold (these thresholds are not equal). Thus, the output of the Schmitt trigger is a clean digital signal, while the sensed signal is a lot more sloppy.

Conclusion

Fibre optics can be used by experimenters and small users: even Radio Shack (Tandy) has fiber optics kits available. Other suppliers can be found by perusing the ads of this magazine. Edmund Scientific (USA) has a particularly nice selection. ■